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INVESTIGATING THE MECHANICAL PROPERTIES ENHANCEMENT OF SELF-COMPACTING CONCRETE THROUGH GLASS FIBER REINFORCEMENT

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Abstract

This study examines into and juxtaposes the performance of traditional self-compacting concrete (SCC) against an innovative variant fortified with glass fibers when subjected to tension. Renowned for its capacity to seamlessly flow and fill formwork sans external vibration, self-compacting concrete stands out. The incorporation of glass fiber reinforcement into self-compacting concrete holds promise for enhancing tensile strength and bolstering resistance against cracking. The objective is to assess the split tensile strength behavior of self-compacting concrete vis-à-vis the novel glass fiber-reinforced self-compacting concrete. In this experimental investigation, a total of 36 specimens are utilized—18 dedicated to self-compacting concrete and the remaining 18 to glass fiber-reinforced self-compacting concrete. The composition of the self-compacting concrete comprises 43-grade ordinary Portland cement, fine aggregate, coarse aggregate (20mm), with a water-cement ratio of 0.45, and 0.6% superplasticizer added relative to the weight of the cementitious material. Conversely, for the glass fiber-reinforced self-compacting concrete, 3% glass fibers are introduced based on the weight of the cementitious material in self-compacting concrete. Subsequently, the split tensile strength of the concrete specimens is evaluated. The findings reveal a noteworthy 5% increase in the split tensile strength of glass fiber-reinforced self-compacting concrete compared to conventional self-compacting concrete. Statistical analysis of the results is conducted using SPSS, version 26 software. This experimental exploration underscores that M20 grade glass fiber-reinforced self-compacting concrete exhibits superior split tensile strength when juxtaposed with conventional M20 grade self-compacting concrete.

Keywords: *Split tensile strength, Strength behavior, Novel glass fiber-reinforced self-compacting concrete, Ordinary Portland cement, Glass fiber, Self-compacting concrete.*

Introduction

Concrete stands as a fundamental material in the construction industry, comprising cement, fine aggregate, coarse aggregate, water, and admixtures. Self-compacting concrete, achieved when concrete reaches a slump of 160mm, is also known as self-consolidating concrete (De Schutter et al., 2008). When glass fiber is incorporated into self-compacting concrete, it becomes glass fiber reinforced self-compacting concrete. This study aims to compare the split tensile strength behavior of self-compacting concrete with that of glass fiber reinforced self-compacting concrete.

Typically, self-compacting concrete consists of 43-grade OPC cement, fine aggregate (M-sand), coarse aggregate (20mm), with a water-cement ratio of 0.45, and 0.6% superplasticizer added based on the weight of the cementitious material (Wong et al., 2012). In contrast, glass fiber reinforced self-compacting concrete retains the same constituents as self-compacting concrete but includes 3% glass fiber added relative to the weight of the cementitious material. Superplasticizers play a crucial role in reducing the water-cement ratio, enhancing concrete flow, and minimizing aggregate segregation. The benefits of self-compacting concrete are manifold, including improved concrete quality, reduced need for external repairs, accelerated construction timelines, cost savings, automation facilitation in construction, and enhanced durability and reliability of concrete structures (Kostrzanowska-Siedlarz et al., 2022).

Utilizing our team's extensive knowledge and research experience, evidenced by a series of high-quality publications (Prabakaran et al., 2022; Matheswaran et al., 2022; Sakthivadivel et al., 2022; Ramesh et al., 2022; Sundar et al., n.d.; Vellaiyan et al., 2022; Tharanikumar et al., 2022; Vivekanandan et al., 2022), this study aims to provide valuable insights into the topic.

Considerable research has been conducted in the last half-decade focusing on glass fiber reinforced concrete. Notably, Google Scholar boasts close to sixty articles on this subject within the past five years, while ScienceDirect hosts over twenty publications. Among the notable contributions to this field are studies examining the properties and mechanical behavior of glass fiber reinforced self-compacting concrete (Wong, 2012; Rahman, 2012). Additionally, research has explored fiber-reinforced cementitious materials, as exemplified by the work of Mindess et al. in 1991, and experimental analyses of the punching shear capacity in large-scale GFRP-reinforced flat slabs made of synthetic fiber-reinforced self-compacting concrete, as demonstrated by AlHamaydeh et al. in 2021.

While previous research efforts have predominantly focused on fiber-reinforced cementitious materials with lower fiber content, this study takes a step further by incorporating a higher proportion of glass fibers, amounting to 3%, alongside M sand as fine aggregate. Moreover, the investigation encompasses a comparative analysis of the split tensile strength behavior of conventional self-compacting concrete and glass fiber reinforced self-compacting concrete. Notably, the examination does not encompass the combination of M20 grade self-compacting concrete with 0.6% superplasticizer and 3% glass fiber reinforced self-compacting concrete, signifying a research gap in this domain.

This study endeavors to bridge this gap by scrutinizing the impact of this specific combination on the concrete's strength characteristics. Through experimental testing conducted over a curing period of 28 days, the split tensile strength behavior of concrete specimens is meticulously evaluated, considering the influence of admixtures and steel fibers. Such a rigorous analysis is expected to yield valuable

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insights into the strength behavior of the concrete, potentially elucidating the benefits offered by the proposed combination in terms of enhanced mechanical properties and overall performance.

2. Materials and Methods

This study was conducted in the concrete laboratory of the Department of Civil Engineering at Indira Gandhi Institute of Engineering and Technology. Two sets of experiments were carried out as part of this investigation. In the first set of experiments, concrete specimens of M20 grade self-compacting concrete were prepared. These specimens were formulated with 0.6% of superplasticizer, along with the appropriate proportions of aggregates and water, as specified by the design mix for M20 grade self-compacting concrete. In the second set of experiments, another group of concrete specimens was prepared using the same 0.6% of superplasticizer. However, in this case, an additional 3% of glass fiber was added to the mix, along with aggregates and water, following the design mix for M20 grade self-compacting concrete. The calculations for sample size determination were performed using a G-power of 0.8, with alpha and beta values set at 0.05 and 0.2, respectively, and a confidence interval of 95%. The Independent sample T-Test was utilized with a significance level of $p=0.001$ ($p<0.05$), yielding a p-value of 0.0321. The quantities of materials used in each mix are detailed in Table 1. Additionally, Table 2 provides information on the properties of the cement used, while Table 3 outlines the properties of the coarse aggregate. Furthermore, Table 4 presents the properties of the fine aggregate employed in the experiments.

Table 1. Properties of cement

S.no.	Material	Weight (kg)
1	Cement	0.67
2	Coarse aggregate	2.13
3	Fine aggregate	1.22
4	Fiber	0.020
5	Water	0.298

Table 2. Properties of Cement

S.no	Properties of cement	Results
1	Fineness of cement	85 Microns
2	Standard consistency	32%
3	Specific gravity	3.3
4	Initial setting time	32 min
5	Final setting time	9.5 hrs

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Table 3. Properties of Coarse Aggregate

S.no	Test	Results
1	Sieve analysis	4.35
2	Specific gravity	2.63
3	Size	4.80mm
4	Water absorption	3.1%

Table 4. Properties of Fine Aggregate

S.no	Test	Results
1	Sieve analysis	3.25
2	Specific gravity	2.70
3	Size	19mm
4	Water absorption	3.3%

Cement: Consistently sourced from a single batch, 43-grade Bharathi cement, a standard variety of ordinary Portland cement, was employed throughout the research to ensure uniformity. The focus remained on utilizing top-quality cement for all experimental procedures.

Fine Aggregate: M-Sand, readily available in the local area, served as the fine aggregate, passing through a 4.75mm sieve. The fineness modulus of the M-Sand ranged between 2.6 and 2.9, meeting the required specifications for particle size distribution.

Coarse Aggregate: For projects necessitating a coarse aggregate size of 20mm, crushed stones meeting IS Sieve standards of 80mm, 40mm, and 20mm were meticulously selected and utilized in accordance with project requirements.

Water: Normal tap water sourced from the local region was employed for concrete mixing, maintaining a consistent water-cement ratio of 0.45, as per established industry standards.

Superplasticizer: To enhance the workability and flow properties of the concrete mix, high-grade superplasticizer, specifically Adhere Mix 700, was added as an admixture.

Fibers: Glass fibers, depicted in Figure 1, were introduced into the concrete mixtures to provide reinforcement and improve the mechanical properties of the resulting concrete specimens.

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Figure 1: Glass fibers (20mm in length)

Materials were precisely calculated and arranged using weight batching procedures. The constituents employed for sample preparation included Ordinary Portland Cement, M-sand utilized as fine aggregate, 20mm crushed stones employed as coarse aggregate, 0.6% Adhere Mix 700 high-grade superplasticizer, 3% glass fiber, and water.

After meticulous mixing to ensure uniformity, the composite was transferred into cylindrical molds measuring 10cm in diameter and 20cm in height. A total of 18 samples were fabricated for self-compacting concrete, alongside an equivalent number of samples for the innovative glass fiber reinforced self-compacting concrete variation.

Following preparation, all 36 samples were positioned in a curing tank for a period of 28 days to facilitate optimal curing conditions. Upon completion of the curing duration, the cylinders were removed from the tank and subjected to sunlight until thoroughly dried.

Subsequently, the weight of each sample was recorded, and the samples were subjected to testing using a split tensile machine, as depicted in Figure 2.

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Figure 2: Machine for split tensile testing

3. Statistical Analysis

During the statistical analysis phase, the research employed the Statistical Package for the Social Sciences (SPSS), version 26 software, to conduct a comprehensive examination of the obtained data. This powerful analytical tool facilitated a meticulous investigation into the differences between the self-compacting concrete and glass fiber reinforced self-compacting concrete groups. Through the application of separate sample T-Tests, the study aimed to discern any significant variations in the analytical outcomes between these two groups. In this study, a range of independent variables were considered, each playing a distinct role in influencing the outcomes. These variables encompassed crucial factors such as split tensile strength, the grade of concrete, water/cement ratio, grade of cement, and days of curing. By examining these independent variables, the research sought to unravel the intricate relationships and influences impacting the performance of the concrete specimens.

Utilizing the SPSS software, various statistical parameters were calculated to provide a comprehensive understanding of the data. These parameters included the mean, which offers insights into the central tendency of the data; the standard deviation, indicating the dispersion or spread of the data points around the mean; and the standard error of the mean, providing an estimate of the variability of the sample means. By meticulously analyzing these statistical metrics, the study aimed to derive valuable insights into the split tensile strength characteristics of the concrete samples. The utilization of advanced statistical techniques and software played a pivotal role in unraveling the complexities of the data, enabling the research to draw robust conclusions regarding the performance of self-compacting concrete and glass fiber reinforced self-compacting concrete under tension.

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4. Results

In the experimental study, the mean split tensile strength behavior of both self-compacting concrete and novel glass fiber reinforced self-compacting concrete was meticulously calculated. The findings revealed that the mean split tensile strength of self-compacting concrete stood at 4.99N/mm^2, while that of novel glass fiber reinforced self-compacting concrete exhibited a slightly higher value of 5.39N/mm^2. This observation indicated that in the experimental conditions, the glass fiber reinforced self-compacting concrete demonstrated superior tensile strength compared to conventional self-compacting concrete. In fact, the incremental improvement in split tensile strength was measured at 5%. Further analysis of the statistical parameters corroborated the significance of these findings. Table 7 presented in the study elucidated the key statistical metrics, revealing a notable disparity between the two groups. Notably, the standard deviation values for both groups were observed to be quite low, indicative of a relatively tight distribution of data points around the mean. Specifically, the standard deviation of self-compacting concrete was determined to be 0.414, while that of glass fiber reinforced self-compacting concrete slightly higher at 0.677. These minimal deviations underscored the consistency and reliability of the experimental results. It is worth noting that self-compacting concrete, comprising cement, fine aggregate, coarse aggregate, water, and superplasticizer, formed the basis of comparison in this study. The incorporation of glass fibers into the self-compacting concrete matrix yielded significant enhancements in tensile strength, as evidenced by the experimental findings and statistical analyses.

Table 5. The Split Tensile Strength of Group-1 Samples

S.No	Weight of the Cylinder (in Kg)	Collapse Load (KN)	Split Tensile Strength of Self-Compacting Concrete (N/mm^2)
1	4.030	87	5.540
2	4.011	74	4.712
3	4.197	71	4.520
4	4.187	73	4.648
5	4.096	78	4.966
6	4.002	70	4.456
7	4.118	81	5.157
8	4.097	83	5.284
9	4.001	78	4.966
10	4.018	78	4.966
11	4.018	80	5.088
12	4.108	90	5.730
13	4.097	83	5.284
14	4.096	74	4.712
15	4.002	78	4.966
16	4.118	69	4.392
17	4.098	90	5.730

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Table 6. Split Tensile Strength of Group-2

S.No	Weight of Cylinders (Kg)	Collapse Load (kN)	Split Tensile Strength of Fiber Reinforced Self-Compacting Concrete (N/mm^2)
1	4.110	94	5.985
2	4.120	99	6.303
3	4.200	108	6.876
4	4.000	76	4.838
5	4.070	77	4.902
6	4.057	74	4.711
7	4.000	83	5.284
8	4.180	87	5.539
9	4.130	85	5.412
10	4.010	106	6.749
11	4.030	70	4.456
12	4.000	82	5.221
13	4.060	81	5.415
14	4.120	78	4.966
15	4.090	80	5.093
16	4.060	80	5.093
17	4.070	77	4.902
18	3.990	83	5.284

Table 7. Comparison of Glass Fiber Reinforced Self-Compacting Concrete & Self-Compacting Concrete

Groups	N	Mean	Std Deviation	Std. Error Mean
Glass Fiber Reinforced Self-Compacting Concrete	18	5.39	0.677	0.160
Self-Compacting Concrete	18	4.99	0.414	0.098

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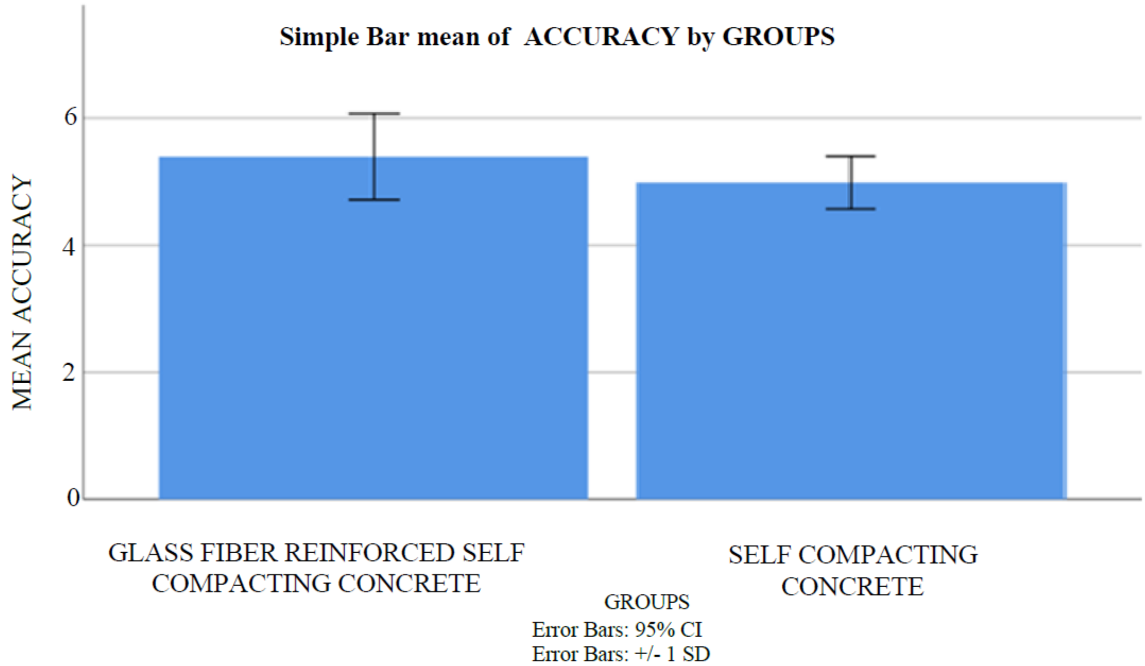

Fig. 3 Bar chart representing the comparison of mean split tensile strength of GFR SCC & SCC

Table 8. Mean, Standard Deviation, and Significance Difference.

Accuracy	Independent Samples Test								
	Levene's Test for Equality of Variances					T-test for Equality of Means			
	F	Sig	t	df	Sig(2 – tailed)	Mean Difference	Std.Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Equal variances are assumed	2.349	0.135	2.179	34	0.036	0.407	0.187	0.027	0.787
Equal variances are not assumed.			2.179	28.149	0.038	0.407	0.187	0.027	0.790

Similarly, the novel glass fiber reinforced self-compacting concrete comprises cement, fine aggregate, coarse aggregate, water, superplasticizer, and glass fiber. Table 5 delineates the split tensile strength values of self-compacting concrete, while Table 6 presents the corresponding values for novel glass fiber reinforced self-compacting concrete. Group statistics elucidating these findings are detailed in Table 7.

The outcomes of the independent samples t-test are outlined in Table 8. Additionally, Figure 1 illustrates the incorporation of steel fiber in concrete, whereas Figure 2 depicts a split tensile strength machine.

In the statistical analysis, Fig. 3 showcases the comparison of mean accuracy values between the two groups of glass fiber reinforced self-compacting concrete and conventional self-compacting concrete. With a p-value of 0.05 and an error bar of 95%, the effective prediction is depicted. The error bars, denoting the mean accuracy detection +/- 1 SD, provide insights into the variability of the data.

Discussion:

The weight of self-compacting concrete surpasses that of glass fiber reinforced self-compacting concrete. The inclusion of glass fiber facilitates a reduction in coarse aggregate content in the concrete mixture, resulting in a lighter weight compared to conventional self-compacting concrete. Notably, self-compacting concrete is characterized by its non-segregating nature, facilitating placement solely through the force of gravity. Similarly, glass fiber reinforced self-compacting concrete exhibits a high flow ratio while mitigating segregation, albeit at a reduced aggregate content and flow ratio compared to conventional self-compacting concrete.

Upon determining the split tensile strength of both concrete types, it was observed that self-compacting concrete yielded a mean split tensile strength value of 4.99N/mm^2, whereas glass fiber reinforced self-compacting concrete demonstrated a higher mean of 5.39N/mm^2. This highlights the enhanced strength properties conferred by glass fiber reinforcement. In glass fiber reinforced self-compacting concrete, the incorporation of 3% glass fiber and 0.6% high-grade superplasticizer (Adhere Mix 700) contributes to improved water resistance within the concrete matrix.

Several factors influence the split tensile strength of concrete, including water-cement ratio, cement quality, aggregate and fiber size, water penetration, and the presence of excess superplasticizer. Limitations concerning these affecting factors include the utilization of smaller size coarse aggregates (10mm-20mm), ensuring an optimum fiber dosage in glass fiber reinforced self-compacting concrete, utilizing higher-grade concrete (at least M20 grade), and restricting the use of superplasticizer within the range of 0.6% to 1%.

Looking ahead, the potential applications of glass fiber reinforced self-compacting concrete are vast. It can be effectively employed in high-rise buildings, bridges, precast sections, beams, and columns, offering extended lifespan and enhanced load-carrying capacity.

Conclusion

This study undertook a comparative analysis of the split tensile strength between glass fiber reinforced self-compacting concrete and traditional self-compacting concrete. As illustrated by the experimental findings, the inclusion of glass fiber reinforced self-compacting concrete exhibited superior split tensile strength when compared to its conventional counterpart. Specifically, there was a notable 5% increase in split tensile strength observed. These results hold promise for the construction industry, suggesting that structures built with glass fiber reinforced self-compacting concrete may possess enhanced load-bearing capabilities and prolonged lifespans. Moreover, the incorporation of

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glass fibers serves to mitigate moisture content within the concrete, further augmenting its durability and resilience.

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